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Selected Papers
from the
BUREAU of
RADIOLOGICAL HEALTH
Seminar Program

PAST and PRESENT STATUS of RADIATION PROTECTION:

a comparison

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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Consumer Protection and Environmental Health Service
Environmental Control Administration

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SELECTED PAPERS from the BUREAU of RADIOLOGICAL HEALTH SEMINAR PROGRAM

FOREWORD

The Bureau of Radiological Health, formerly the National Center for Radiological Health, carries out a nationwide program designed to reduce the exposure of man to hazardous ionizing and nonionizing radiation.

Within the Bureau, the Office of Information disseminates information about the significant events occurring in the field of radiological health. In pursuit of this mission, the Office conducts a program of seminars and symposia. When a presentation is believed to be of especial interest, the speaker is invited to publish in this series entitled "Selected Papers from the Bureau of Radiological Health Seminar Program."

The Bureau also publishes the monthly **Radiological Health Data and Reports,** and special division technical reports. These publications are intended to provide a vehicle for conveying the results of radiological health studies to audiences which have specific interests.

The Selected Papers are distributed to State and local radiological health program personnel, Bureau technical staff, advisory committee members, university radiation safety officers, libraries and information services, industry, hospitals, schools, and other interested individuals. These reports are also included in the collection announced and made available by the Clearinghouse for Federal Scientific and Technical Information.

I encourage the readers of these reports to inform the Bureau of their opinions of these papers and of their value to the radiological health community.

John C. Villforth
Director
Bureau of Radiological Health

Carl B. Braestrup
Consultant, Radiological Physicist
Lenox Hill Hospital
New York, New York

Mr. Braestrup, a native of Copenhagen, came to the U.S.A. in 1918 and graduated from Massachusetts Institute of Technology in 1922. During the next four years he worked as an electrical engineer with various x-ray companies.

In 1926, he was appointed to the staff of the Post Graduate Medical School and Hospital of New York to fill the position vacated by Dr. Otto Glasser, pioneer x-ray physicist. In this position Mr. Braestrup became actively engaged in x-ray measurements.

From 1929 to 1966, he was Director of the Physics Laboratory, Department of Hospitals, New York City. He was responsible for the radiation safety of the employees in some 25 hospitals. During this period, he was also a consultant to a number of private hospitals and government agencies. Mr. Braestrup continued his education by taking postgraduate courses in physics at New York University and subsequently became an Associate Professor of Radiology (Physics) at this school.

In 1950 the Physics Laboratory moved to the newly completed Delafield Hospital, an affiliate of Columbia University. Here, the then up-to-date laboratory and radiation therapy facilities, planned by Mr. Braestrup, were used for extensive studies on dosage distribution and radiation protection.

Since his retirement as the Director of the Francis Delafield Hospital Physics Laboratory, Mr. Braestrup is serving as a consultant to the Lenox Hill Hospital (New York) and, in a private capacity, as a consultant for the planning of a number of medical and industrial radiation facilities.

For the past 20 years Mr. Braestrup has been active on a number of national and international committees on radiation protection and measurements. He served on the Board of Directors of the NCRP for many years and is currently Chairman of its Committee on Shielding Design.

Mr. Braestrup became a U.S. citizen in 1924, is married, and has two children and five grandchildren.

PAST AND PRESENT STATUS OF RADIATION PROTECTION: A COMPARISON[1]

Carl B. Braestrup

INTRODUCTION

This presentation is based mainly on personal experiences in the field of radiation protection over a period of some 40 years. The detailed history of the tolerance dose, now called the Maximum Permissible Dose (MPD), is given in several publications and only the principal aspects of its development will be discussed here. (1, 2)

The past status of x-ray protection may be divided into three periods. The first period began with Roentgen's discovery in 1895 and concluded about World War I. During that time only gas x-ray tubes were available. Since the operation of these tubes required considerable skill, their use was consequently limited; unfortunately, so also were the protective measures limited.

A second period started with the development of the hot filament or Coolidge type of tube. This type of tube greatly simplified the operation of x-ray equipment and resulted in the installation of such apparatus by many nonradiologists. Until about 1935 the greatest hazard associated with x-ray equipment was electrical due to the exposed high tension wires within reach of the patient. This hazard was practically eliminated with the construction of shock proof, radiation protective equipment. Unfortunately, such apparatus was often described as "ray proof," giving the impression that no other radiation safety measures were required. It is, therefore, not surprising that radiation injuries continued to occur. Typical cases will be discussed later.

EARLY SKIN INJURIES

The harmful effects of overexposure to x-rays were recognized almost immediately after Roentgen's announcement of his discovery. Within a month, by the end of January 1896, Dr. E. H. Grubbe developed dermatitis on his hands due to radiation received while working with x-ray tubes. (3, 4) While Dr. Grubbe lived to the age of 84 years, he suffered numerous and painful injuries; he lost his left hand, forearm, and part of his face because of overexposure to x-rays.

A number of other "x-ray burns" were reported within the first few years of Roentgen's discovery. (5) Among the victims were patients, operators, experimenters and demonstrators of x-ray equipment. With the radiographic equipment then available, patients received doses of the order of 1000 times that required today. The lack of intensifying screens, the low tube potential, and the low sensitivity of the single coated photographic plate, then in use, necessitated long exposure times. Thirty to sixty minutes were commonly used for radiographs of heavy parts of the body (this notwithstanding the use of short target-film distances). Usually the x-ray tube was as close to the patient as possible without causing spark-over from its high tension terminals. No filters were used and the inherent filtration of the tube wall was low, generally about 0.2 mm Al equivalent. As might be expected many of the patients did develop skin injuries. Codman of Harvard Medical School reported (in 1902) seventy cases of accidental x-ray burns. (6) His paper was based on cases recorded in the medical literature here and abroad. In another article he described one of the first legal suits involving x-ray injuries. (7) The manufacturer of the equipment had warranted that his apparatus would not cause burns and had to pay $6,750 damages for injuries suffered by a patient.

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[1]**This paper was presented as a part of X-Ray Exposure Control Laboratory's (National Center for Radiological Health) Seminar Program on June 2, 1967 in Rockville, Maryland.**

For many years skin injury was considered the principal, if not the only hazard associated with x-rays. The erythema dose (300-400 rads) was assumed to be the upper limit for irradiation of patients and personnel. The fact that the individual did not develop an erythema was accepted as evidence of adequate protection. The skin, in these earlier times, served as a personnel monitor just as the film badge does today. Fortunately, the ratio of the dose to the deeper seated tissue to that of the skin surface was considerably less than it is today. The tube potential was lower and the radiation less homogeneous because of the low inherent filtration of the tube and the practice of using thin or no added filtration.

As late as 1929, reports were published in which the adequacy of room shielding was discussed in terms of the number of radiographic examinations required to produce a skin reaction to persons in adjacent rooms. (8)

SYSTEMIC INJURIES

Although skin injuries received the greatest attention, many other deleterious effects were reported within a decade of Roentgen's discovery. These are outlined in Table 1 and will be discussed under the various x-ray applications.

FLUOROSCOPY

Of the various x-ray procedures, fluoroscopy caused the greatest exposure to patient and staff. This was particularly true when non-protective fluoroscopes were used. Fig. 1 shows the results of radiation measurements made on a non-shock proof vertical fluoroscope and of those made on protective type of equipment. It will be seen that the stray radiation levels on old type fluoroscopes were 3 to 10 times greater. In addition, the use of protective aprons has reduced further the average dose to the greater part of the fluoroscopist's body by a factor of about 20.

The exposure to the patients has been reduced even more drastically. The output of one popular vertical fluoroscope (Wappler), which was manufactured around 1930-1935, was 125 - 150 R/min at the panel. This is about 100 times the exposure rate generally used today with image intensification. Skin reactions from fluoroscopy were not unusual in those days. Several were so severe that they caused permanent injuries and resulted in legal actions being brought against the fluoroscopists.

To minimize the hazards, a 100 R per examination limit was set in the New York City hospitals. This was accomplished by an automatic timer and a stop which limited the tube current to 5 mA.

While present image intensifiers have reduced the dose to the patient and improved the diagnostic value of the image, some of the earlier models did not provide enough shielding for the fluoroscopist. This is shown in Fig. 2, which illustrates the need for careful radiation surveys of all new equipment.

Table 1. Radiation injuries

A.	**Somatic (depending on individual dose):**
	Skin tumors
	Epilation
	Leukemia and other forms of cancer
	Reduced fertility
	Reduced life span
	Mental anxiety
B.	**Genetic (depending upon population gonad dose):**
	Mutations affecting descendants of irradiated persons

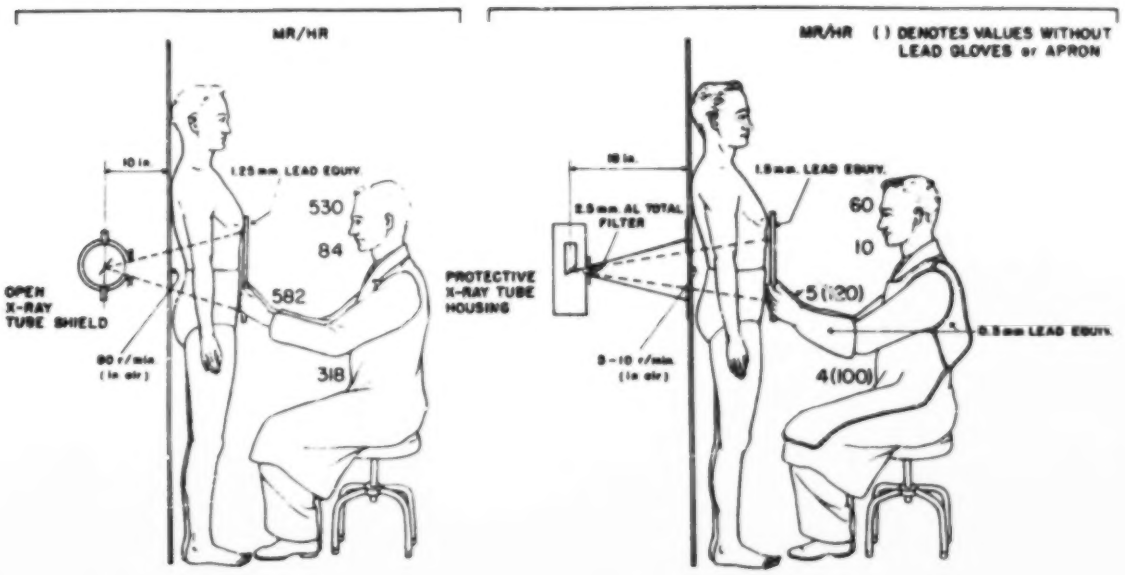


Fig. 1 Comparison of radiation measurements. On the left, nonprotective vertical fluoroscope in common use in 1930; on the right, protective types are still used today. The figures indicate the exposure rates in mR/hr. On the right, the values obtained without protective apron or gloves are shown in parenthesis.

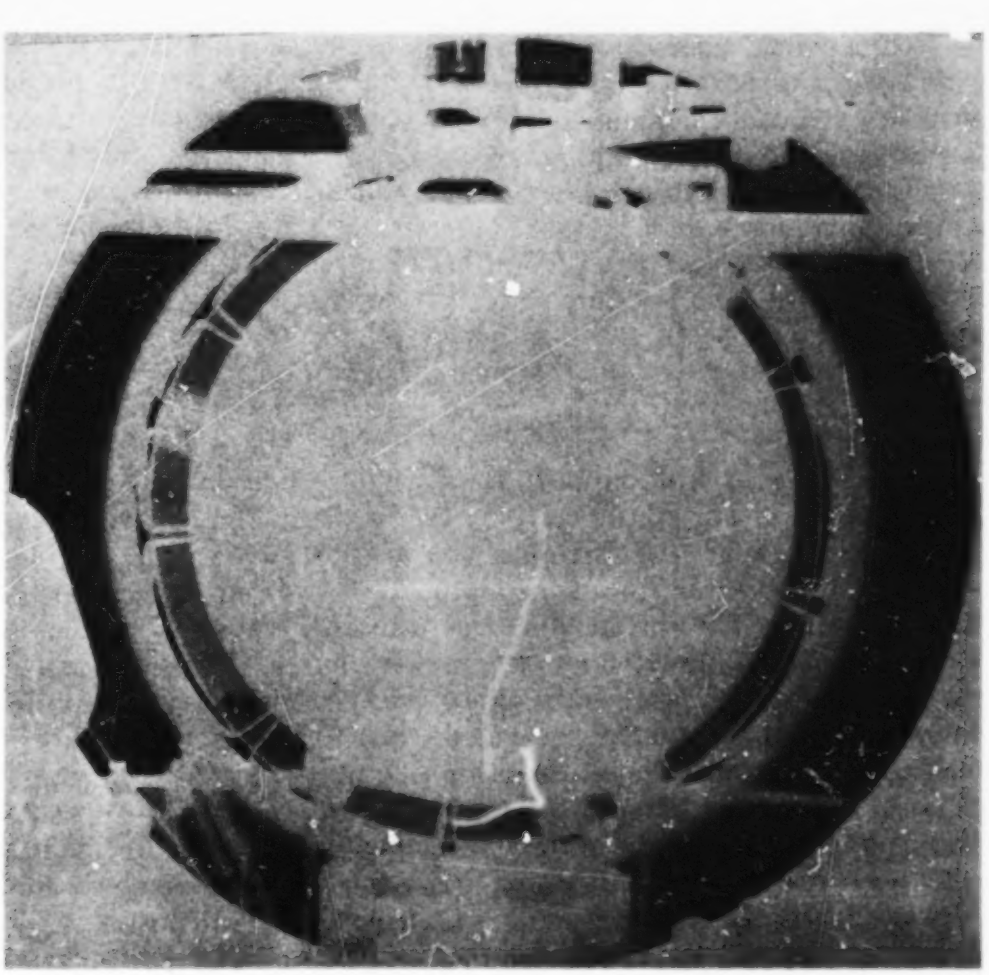


Fig. 2 Radiograph showing radiation transmitted through intensifier housing when the film was placed on top of housing. Densitometric evaluation indicated an exposure rate of 600 mR/hr. (Courtesy of R. T. Mooney)

The hand fluoroscope (a fluoroscopic screen with lead glass and a hood to exclude light) was probably the most hazardous x-ray accessory used during the 1930-1940 period. It was used extensively in conjunction with portable x-ray equipment to set fractures. Many patients and physicians suffered permanent skin injuries and some even lost limbs as a result of the high doses resulting from the short target-skin distances and long exposure times used.

RADIOGRAPHY

During the past decades there has been a progressive reduction in the amount of radiation required for a given radiographic procedure. This increased efficiency has been due mainly to improvements in equipment, accessories, darkroom facilities and, most importantly, in operating techniques. Unfortunately, even at the present time, these factors are not always given adequate consideration.

Typical is a recent incident in which several women received definite skin reactions from an unfiltered beryllium window x-ray tube used for mammography. This again emphasizes the need for complete radiation measurements before new apparatus, or techniques, are used clinically. In the past such incidents happened frequently and often because the same persons were radiographed repeatedly for test or demonstration purposes. At one x-ray company several shipping boys suffered loss of hair from such practices.

Prior to World War II, shielding of diagnostic x-ray rooms was the exception rather than the rule. The protection was usually limited to a lead lined floor screen intended to protect the operator. Quite often the screen was placed so that it provided better shielding for the control booth than for the technician. Even today the control booth is not always placed within the radiographic room so the open end is in the direction of minimum sources of scattered radiation. There are still many installations in which the edge of the lead glass window is too close (less than 18 inches) to the edge of the lead lined partition, and thus, the operator's body may be exposed to significant scattered radiation.

When x-ray installations are constructed with nonmasonry wall or wooden floors, the lack of structural protection has frequently resulted in irradiation of persons in nearby areas. These exposures have, in many instances, been in excess of present permissible doses.

THERAPY

The safety in x-ray therapy has improved greatly in recent years. Perhaps one of the most important factors has been the increased use of alternate methods in the treatment of many types of nonmalignant diseases.

For instance, until a few years ago x-rays were used extensively in the treatment of ringworm of the scalp. At just one New York medical center, a total of about 10,000 children were treated by producing temporary epilation. This was done by exposing the head through five large fields with 300-400 R to each. Only the eyes of the child were shielded. It is evident that this form of irradiation has added significantly to the population gonad dose, not to mention the possibility of somatic injuries to the child. Fortunately, the use of x-rays for this purpose has been discontinued at most clinics.

Some 40 years ago Roentgen rays were actually used by beauty shops in the eastern United States for the treatment of superfluous hair. Only a few of the irradiated women escaped some injury to their skin or deeper tissues. (9)

Lack of appropriate room shielding was another cause of unnecessary irradiation of the public. Even with equipment operating at 200 kV, the use of a protective tube housing was often thought to be sufficient. For instance, some 30 years ago at a well known Baltimore hospital, no structural lead shielding was provided for their 200 kV installation. Measurements demonstrated the exposure rate to be 2700 mR/hr on the floor below and 710 mR/hr in adjacent rooms. This condition was discovered and corrected within one year of operation; however, other installations were

found to have been operating for years with radiation levels of several hundred mR/hr in adjacent occupied areas. (10)

Today most radiation shielding is designed by experienced radiological physicists to meet the MPD as recommended by the NCRP. For this reason inadequate structural shielding is less likely to be found in installations. When it occurs, it usually can be ascribed to one or more of the following causes:

Type of use or equipment different from that originally specified

Recessed ducts, switch boxes, etc. not lead shielded to compensate for reduced concrete thickness

Concrete density less than specified

Defective workmanship causing leakage at joints, doors, and lead glass windows

TESTING OF X-RAY TUBES AND EQUIPMENT

Visual inspection of gassy x-ray tubes during irradiation was quite common prior to the use of enclosed tube housings. Many repairmen, therefore, routinely received significant exposures. In most cases, however, the doses were not high enough to produce visible skin changes.

A notable exception was a 26 year old service engineer who, in 1926, was operating an x-ray therapy tube rated at 200 kV and 30 mA. The tube was enclosed in an adequately shielded lead drum. Unfortunately, he decided to open the door of the drum in order to more accurately locate the cause of the unsteady operation of the tube. He subsequently lost the hair on his chest, face and forehead and the skin of his face showed a definite erythema. The affected areas did not require shaving for several weeks which indicated that he had experienced a dose of more than 400 rads.

The skin injuries served as a warning to the engineer and those who saw him soon after the incident. However, he suffered no obvious latent effects and was active in the x-ray business until recently. He married a few years after the incident and is the father of three healthy children. He was spared mental anxiety because little consideration was given to systemic injuries at that time. Today such an accident is less likely to happen but, if it did, the psychological impact might affect the entire life of the victim.

The measurement of output from an x-ray tube involved some hazard at that time. The condenser R-meter had not been developed and the ionization chamber was permanently attached to an electrometer. With the Wulf iontoquantimeter that Dr. Otto Glasser, and later I, used, it was possible to observe the scale through the lead glass window of the room. With the commonly available types of instruments, the physicist had to be in the x-ray therapy room to charge up and read the meter. Even though he was partially shielded by a lead rubber apron, certain parts of his body received a significant dose.

Electron Tubes

It has long been recognized that any electron tube operating above a few kV is a potential source of x-rays.

Rectifying Tubes

The radiation hazard received very little attention when mechanical rectifiers were replaced with electronic ones around 1930. Unshielded rectifying tubes were often located on top of the high tension transformer and close to the operator. Under normal operation, the x-ray emission is low because the potential across the tube during the useful part of the cycle is less than one kV. However, if the tube is gassy, or the filament current too low, the x-ray exposure rate may exceed several hundred mR/hr at nearby areas. Today the valve tubes of x-ray machines are usually oil-immersed with the transformer and well are shielded by a steel tank.

Other types of rectifying tubes are being used to an increasing extent in a variety of

electrical devices. Effective shielding is required to ensure adequate x-ray protection for any operating condition.

Television

An incident 20 years ago alerted the TV industry to the possible hazards of x-ray emission from the picture tube. A customer in Bridgeport, Connecticut bought a kit to assemble his own TV set. He succeeded in making it work but, in the process, developed a skin rash on his face and hands. His doctor diagnosed the rash as x-ray burns and his lawyer immediately started legal action against the TV manufacturer.

Measurements made with a large condenser chamber, developed especially for this particular legal action, showed an x-ray emission of less than 0.1 mR/hr at the surface of the picture tube. Since an x-ray exposure of 300 to 400 R is required to produce an erythema, other possible causes were investigated. The Yale Medical Department later determined that he was allergic to the soldering flux.

As a result of this incident, most of the TV manufacturers now have tests performed on all new TV models to check for x-ray emission. Since the picture tube potential has been progressively raised from less than 10 kV then to about 25 kV in new models, the problem of x-ray emission has become one of increasing importance. The NCRP recognized this in 1959 and recommended a limit of 0.5 mR/hr at 5 cm from any readily accessible surface of home television receivers under normal operating conditions.

Recent measurements made on representative picture tubes indicate that most American manufacturers meet this limit with a high factor of safety at the normal operating potential of 25 kV. As indicated in Fig. 3, however, the x-ray emission increases greatly with even a slight rise in potential. This is a problem which will require further consideration.

NONMEDICAL APPLICATIONS

Industrial Radiography

Fig. 4 shows the results of a radiation survey made in 1935 on a 400 kV open installation used for radiographing high pressure vessels. To save time the x-ray tube was kept continuously energized and a lead shutter was used to intercept the beam during the placement and removal of the films. The encircled figures indicate the mR/hr exposure levels when the shutter was closed. It can be observed that the leakage radiation was very high and the common practice of leaning against the tube head between exposures was quite hazardous by present standards.

The worker who placed the films was instructed to remain about nine feet from the beam while the shutter was open, but there was no way to visually check the shutter and personnel monitoring was not used at that time. Another hazard was the radiation received by welders working in nearby areas.

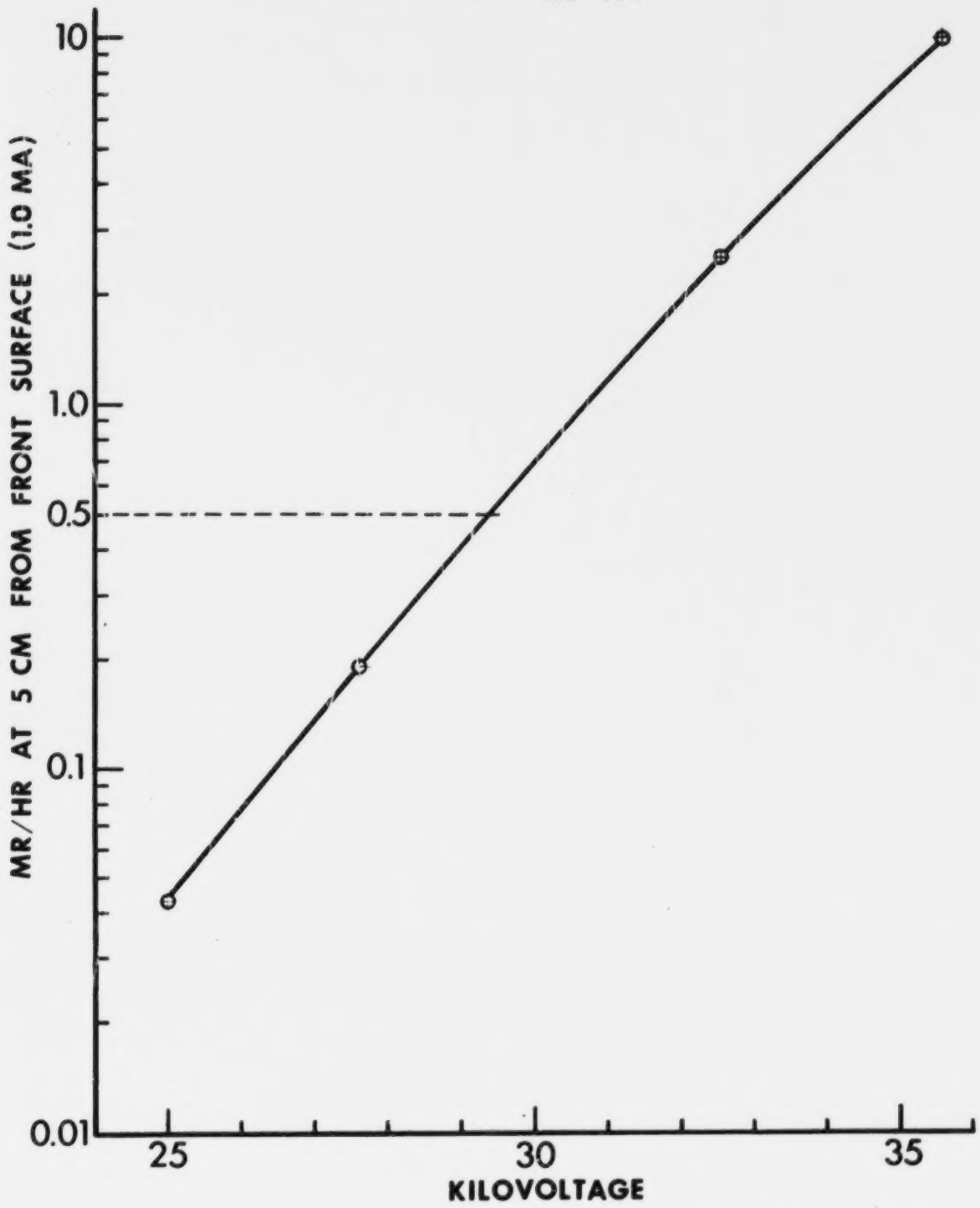
Similar open installations are used today for radiographing pipelines, airplane structures, etc., where enclosed installations would be impractical. However, it is possible to operate such installations with a high degree of safety by the proper use of portable lead shields, fencing off or posting of high radiation areas, and by appropriate personnel monitoring. Since these safeguards take time and effort, they are often likely to be ignored by a careless radiographer.

Diffraction Equipment

During World War II diffraction equipment was used on a production basis for crystal orientation. This was a hazardous operation due to the high exposure rate of the beam (of the order of 100,000 R/min) at the aperture and due to the lack of automatic shutters. As a result, several operators suffered severe skin injuries to their fingers.

At present, automatic shutters are generally provided on diffraction equipment used for routine operations. For research, however,

X-RAY EMISSION FROM REPRESENTATIVE 1967 COLOR PICTURE TUBE RATED AT 25 KV



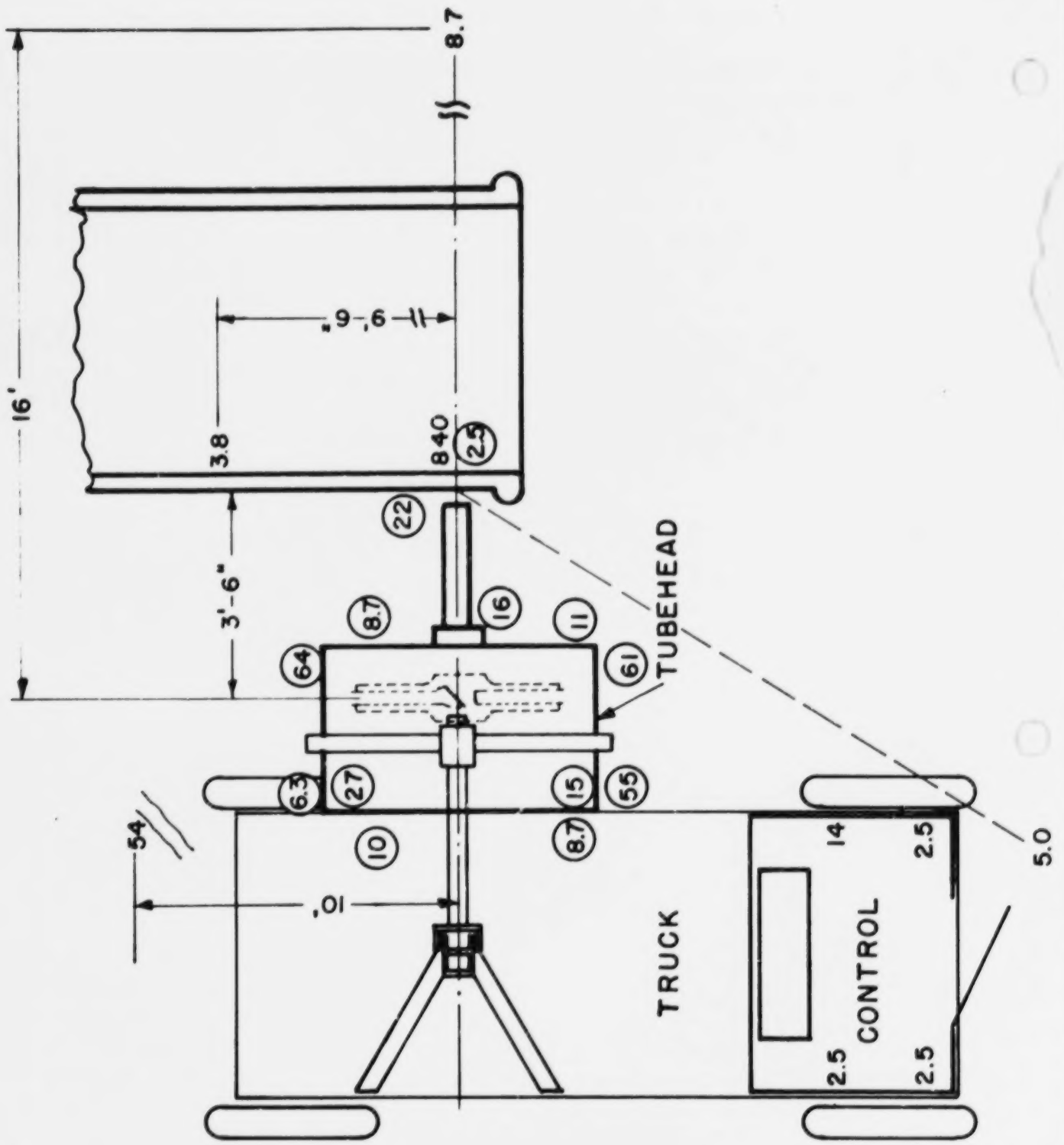


Fig. 4 Result of radiation survey made in 1935 on 400 kV industrial x-ray installation. The figures indicate exposure rates in mR/hr; the encircled figures indicate exposure rates when the beam shutter was closed.

such shutters may interfere and a high degree of dependence for safety is placed on proper operating procedures. For this reason, accidental exposures have not been entirely eliminated.

Personnel monitor readings obviously have only limited meaning when the x-ray beam is extremely narrow. Actually, these readings quite often promote a false sense of security. For the same reason, ionization chamber survey meter readings are of little value except when they are used for the measurement of the scattered and leakage radiation.

Nonmedical Fluoroscopy of Humans

Shoe-fitting fluoroscopes are currently outlawed in most States to eliminate this unnecessary irradiation of the feet which, in the case of children, is particularly objectionable. The exposure rates were quite high (10-50R/min) at the position of the foot. Furthermore, most of the shoe salesmen who operated the equipment had practically no knowledge of the hazards involved.

During World War II many defense plants installed fluoroscopes for the routine inspection of workers to prevent sabotage and theft. The equipment usually had three x-ray tubes to enable the guards to examine the entire body of the employee. The dose per inspection was as high as 50 rads to the skin. Today, this type of fluoroscopy has been almost entirely discontinued except by some governmental agencies.

CONCLUSIONS

Significant progress has been made during the last few decades in reducing the radiation hazards to personnel, patients, and the general public. The NCRP recommendations and their general adoption by regulating agencies have played an important role in these efforts.

The average dose received by radiologists and other radiation workers is now only a few percent of that formerly received. The reduction has been much more drastic than indicated by the progressive lowering of the MPD. Very little attention was given to the "tolerance dose" during the period when it was first introduced; on the other hand, today only a few workers consistently receive doses even approaching the MPD.

Unfortunately, not all the problems have been solved. There is still need for additional improvements in diagnostic x-ray procedures to further minimize the possibility of somatic injuries to the patient and to lower the population gonad dose. Better beam collimation and the elimination of unnecessary and repetitive radiologic examinations are still factors which deserve further consideration.

Every effort should also be made to evaluate and eliminate radiation hazards of new sources of x-rays emitted as an unwanted byproduct. For instance, in recent years the cathode ray tube has been used on an increasing scale for diverse display devices and instruments. At present, the voltage across the tube is generally low (less than 15 kV) and the x-ray emission small. However, many of the tubes are still experimental and often made by small plants which lack competent personnel in the field of radiation protection. If higher potentials are used in the future, these tubes could become significant sources of radiation hazard.

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BRAESTRUP, CARL B.
Past and Present Status of Radiation Protection: A Comparison

U.S. Department of Health, Education, and Welfare, Consumer Protection and Environmental Health Service, Environmental Control Administration, Bureau of Radiological Health. (1969)

ABSTRACT: Significant progress has been made during the last few decades in reducing the radiation hazards (medical and nonmedical) to personnel patients, and the general public. The NCRP recommendations and their general adoption by regulating agencies have played an important role in these efforts.

There is, however, still need for additional improvement in diagnostic x-ray procedures to further minimize the possibility of systemic injuries. Better beam collimation and the elimination of unnecessary and repetitive radiologic examination should be considered further.

Efforts should also be made to evaluate and eliminate radiation hazards of new sources of x-rays emitted as an unwanted by-product.

ACCESSION NO.

KEY WORDS:

Injury

Protection

Diagnostic radiography

Therapy

Fluoroscopy
x-ray tubes

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